NIDL does not certify the Mitsubishi 2020u color monitor as being suitable for IEC workstations. It fails the IEC specification in the following categories: halation by 65%, contrast modulation by 20%, linearity by 20%, moiré by 7%, refresh rate in stereo by 10%, and extinction ratio in stereo by 20%. NIDL rates this color monitor as a "C" in both monoscopic and stereoscopic mode for the Image Analyst and Cartographer applications. This monitor is no longer in production and was recently replaced with the 2040U monitor. The manufacturer recently supplied a 2040U to NIDL. We plan to evaluate it in the near future.

Evaluation of the Mitsubishi 2020u 4 x 3 Aspect Ratio, 21-Inch Diagonal Color Monitor

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Abstract

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CONTENTS

NIDL IEC Monitor Certification Report

## The Mitsubishi 2020u Color CRT Monitor

FINAL GRADES
Monoscopic Mode: C
Stereoscopic Mode: C

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way.

NIDL does not certify the Mitsubishi 2020u color monitor as being suitable for IEC workstations. It fails the IEC specification in the following categories: halation by 65%, contrast modulation by 20%, linearity by 20%, moiré by 7%, refresh rate in stereo by 10%, and extinction ratio in stereo by 20%. NIDL rates this color monitor as a "C" in both monoscopic and stereoscopic mode for the Image Analyst and Cartographer applications. This monitor is no longer in production and was recently replaced with the 2040U monitor. The manufacturer recently supplied a 2040U to NIDL. We plan to evaluate it in the near future.

The Mitsubishi 2020u is a versatile color monitor from the well-regarded Mitsubishi Diamond Pro series that has been on the market for several years. These models incorporate the DIAMONDTRON NF (Natural Flat) aperture grille CRT. NIMA has used a number of the earlier model Mitsubishi color monitors in its analyst workstations.
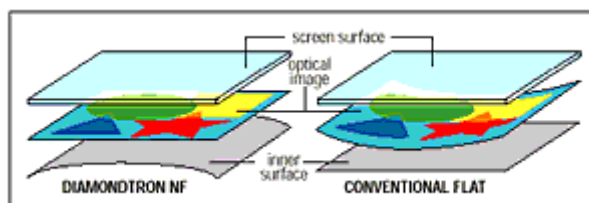
The 4:3 aspect ratio and the 21 inch diagonal give the analyst a large working area. The monitor nearly meets IEC requirements in the monoscopic mode and, according to the manufacturer, will display up to 1800 x 1440 pixels. In the monoscopic mode, halation is 5.8% and contrast modulation is as low as 14% at some screen points so image sharpness may be less than experienced with other competing color displays. In the stereo mode, the refresh rate of 55 Hz per eye and the 11.1:1 extinction ratio are less than required in the IEC specification so stereo performance may be less than experienced with other color displays. Thus, monoscopic and stereo performance of other color monitors NIDL has measured surpasses the 2020U.

The manufacturer lists the maximum addressability as 1880 x 1440 pixels. However, the phosphor pitch of 0.25 to 0.27 mm limits the number of red, green and blue triads that can be addressed to less than 1880 pixels in the horizontal direction. As evaluated, NIDL's measurements for viewable image size of 15.881 x 11.614 inches indicate a maximum of 1494 to 1614 pixels based on the pixel pitch.

The Mitsubishi 2020u monitor is no longer described on the Mitsubishi website.

Evaluation Datasheet

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	Pass
Dynamic Range	24.7dB	25.7 dB	Pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.09 fL	Pass
Luminance (Lmax)	30 fL ± 4%	31.7 fL	Pass
Uniformity (Lmax)	20% max.	17.20%	Pass
Halation	3.5% max.	5.80%	Fail
Color Temp	6500 to 9300 K	9034 K	Pass
Reflectance	Not specified	5.50%	
Bit Depth	8-bit± 5 counts	8-bit	Pass
Step Response	No visible ringing	Clean	Pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 Δ u'v'	0.0041 delta u'v'	Pass
Pixel aspect ratio	Square H = V± 6%	Set to square	Pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.8 ins.	Pass
Cm, Zone A, 7.6"	25% min.	30% (*27%)	Pass
Cm, Zone A, 9.8"	25% min.	23% (*20%)	Fail
Cm, Zone B	20% min.	16% (*14%)	Fail
Pixel density	72 ppi min.	101 ppi	Pass
Moiré, phosphor-to-pixel spacing	1.0 max	1.07	Fail
Straightness	0.5% max ± 0.05 mm	0.30%	Pass
Linearity	1.0% max ± 0.05 mm	1.25%	Fail
Jitter	2 ± 2 mils max.	3.2 mils	Pass
Swim, Drift	5 ± 2 mils max.	4.4 mils	Pass
Warm-up time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	2 mins.	Pass
Warm-up time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	41 mins.	Pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	Pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 2048 (I)	Pass
Lmin	Not specified	0.1 fL	Pass
Lmax	6 fL min ± 4%	6.41 fL	Pass
Dynamic range	17.7 dB min	18.2 dB	Pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 Δ u'v'	0.017 delta u'v'	Pass
Refresh rate	60 Hz per eye, min	55 Hz, per eye	Fail
Extinction Ratio	15:1 min	11.1:1	Fail
AMBIENT LIGHTING			
Dynamic range = 22 dB (158:1)	N/A	3fc	
Dynamic range = 17.1 dB (51:1)	N/A	10fc	

* Denotes Moiré cancellation turned ON

(I) Denotes interlaced scanning

(n) Denotes Nuvision LCD shutter panel

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the Mitsubishi 2020u color CRT high-resolution display monitor. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*

- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998. Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC), August 25, 1999.*

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The Mitsubishi 2020u Color CRT Monitor

Manufacturer's Specifications

According to Mitsubishi, the specifications for the Mitsubishi monitor are:

Specifications	Features
CRT Type	DIAMONDTRON NF (Natural Flat) distortion-free flat screen desktop CRT monitor which reduces external reflection and glare for easier viewing and decreased eye strain.
CRT Size	22" (20.0" diagonal viewable image)
CRT Pitch	0.25 mm - 0.27 mm throughout screen
CRT Faceplate Glass	Optical-quality, anti-static and anti-reflective CRT coating (40% light transmission)
Display Area Size* (W x H)	15.5 x 11.6" (393 x 295 mm)
Maximum Addressable Resolution Format (H x V pixels)	1800 x 1440/80 Hz NI 1600 x 1200/85 Hz NI (recommended) Compatible with IBM, VGA, SVGA, XGA-2, VESA, Apple Macintosh LC, Macintosh II, and Quadra graphics standards.
Auto-Scan Range	H: 30 - 121 kHz V: 50 - 160 Hz
Scan Mode Memory With On- Screen Display	Microprocessor-based. Stores custom and pre-calibrated parameters for up to 26 different modes.
Fully Adjustable Color Balance	5000° - 9950° Continuously variable
Video Clock Frequency	240 MHz
Input Signal	Analog RGB; TTL H/V & C Sync. Separate or composite sync.
Signal Cable	1.8m length, VGA/VGA (D-Sub 9-15HD)
Cable Accessories	Free Apple Macintosh adapter (SD-2) in carton
USB (Universal Serial Bus)	Self-powered USB hub, 3 downstream ports, 2 upstream ports
Power Requirements	100-120 or 220-240 VAC; 50/60 Hz, Auto-sensing all-world power compatibility
Power Consumption	155 W (without USB load) 170 W (with USB load)
Power Cord	1.5 m U.S. version cord with 3P plug
Compact Tilt/ Swivel Base	Integrated with monitor
Dimensions (W x H x D)	19.7 x 19.7 x 19.0" (500 x 500 x 482 mm)
Weight	72.7 lbs. (33 kg)
Packing Carton (W x H x D)	24.8 x 25.1 x 24.5" (630 x 640 x 623 mm)
Shipping Weight	81.5 lbs. (37 kg)
Regulatory Approvals	UL/cUL/DHHS/HWC/FCC-CLASS B/, MPR-II/TCO-95/CE Mark/ TUV-ERGO/EPA/NUTEK
Plug And Play	VESA DDC-1 & 2B
Power Management	VESA DPMS
Warranty/ Support	Three-year parts and labor limited warranty
Corporate Partners Program	48-hour warranty exchange for qualifying accounts.

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:
• Quantum Data 8701 400 MHz programmable test pattern signal generator
• Quantum Data 903 250 MHz programmable test pattern signal generator
• Photo Research SpectraScan PR-650 spectroradiometer
• Photo Research SpectraScan PR-704 spectroradiometer
• Minolta LS-100 Photometer
• Minolta CA-100 Colorimeter
• Graseby S370 Illuminance Meter
• Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter) and Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially-available stereo products:
• Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Section II   PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1600 x 1200 format is.7 dB in a dark room. It decreases to 22 dB (the absolute threshold for IEC) in 2 fc diffuse ambient illumination.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93}. Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene icebox. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Define dynamic range by: DR=10log(Lmax/Lmin)
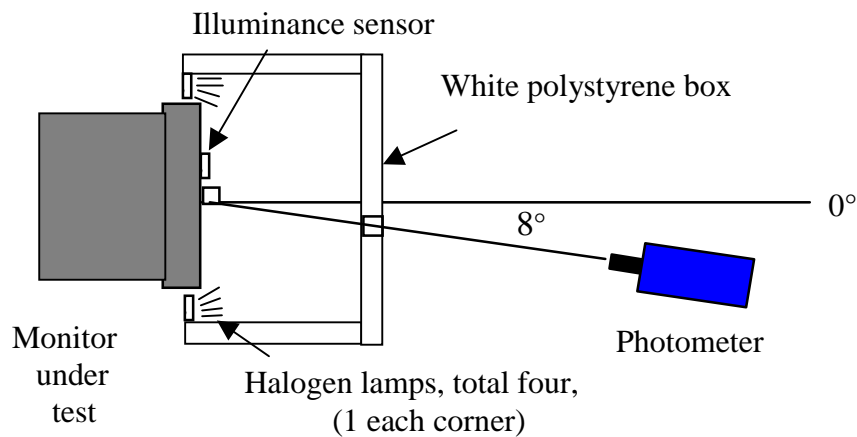
- Top View -

Figure II.1-1. Test setup according to VESA FPDM procedures for measuring
total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate
VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.1 fc
Reflected Luminance	1.1 fL
Faceplate Reflectance	5.5 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. Full screen white-to-black dynamic range decreases from 26.3 dB in a dark room to 22 dB (the absolute threshold for IEC) in 3 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms
Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.09 fL.

	Displayed Addressable Format
Ambient Illumination	**1600 x 1200**
0 fc (Dark Room)	25.7 dB
1 fc	23.5 dB
2 fc	22.1 dB
3 fc	21.1 dB
4 fc	20.2 dB
5 fc	19.5 dB
6 fc	18.9 dB
7 fc	18.4 dB
8 fc	17.9 dB
9 fc	17.5 dB
10 fc	17.1 dB

II.2. Maximum Luminance (Lmax)

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.*

The highest luminance for Lmax was 31.7 fL measured at screen center in 1600 x 1200 format.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range
               measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y
               chromaticity coordinates (CIE 1976) were measured using a hand-held
               colorimeter (Minolta CA-100). The correlated color temperature (CCT)
               computed from the measured CIE x, y chromaticity coordinates was within range
               specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance and Color
Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	9034K	0.283	0.303	31.7 fL

II.3. Luminance (Lmax) and Color Uniformity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 17.2% across the screen. Chromaticity variations were less than 0.004 delta u'v' units.

Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment: • Video generator
                 • Photometer
                 • Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.
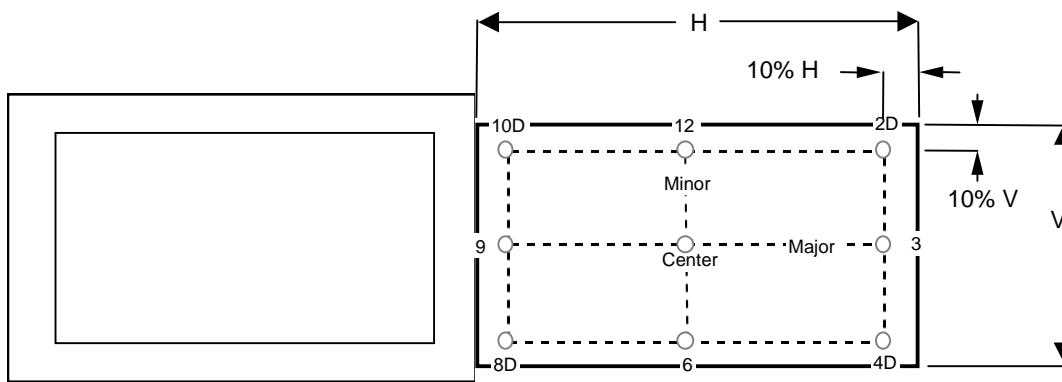
Full Screen Flat Field test pattern.   *Nine screen test locations.*
Figure II.3-1   **Figure II.3-2**

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of Δ u´v´.

Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Use or disclosure of data on this sheet is subject to the restrictions on the cover and title of this report.

Table II.3-1.Spatial Uniformity of Luminance and Color
Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT	CIE x	CIE y	L, fL
center	9034	0.283	0.303	31.7
2	9285	0.281	0.301	30.2
3	9158	0.282	0.302	30.9
4	8779	0.286	0.303	29.7
6	9325	0.281	0.300	30.5
8	9450	0.281	0.297	28.6
9	9543	0.280	0.297	27.3
10	9020	0.284	0.301	28.3
12	9048	0.282	0.305	32.0

```
10      12      2
                     Key to clock
9    CENTER    3     positions used
                     in the tables
8       6       4
```

1600 x 1200

Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity.
(Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

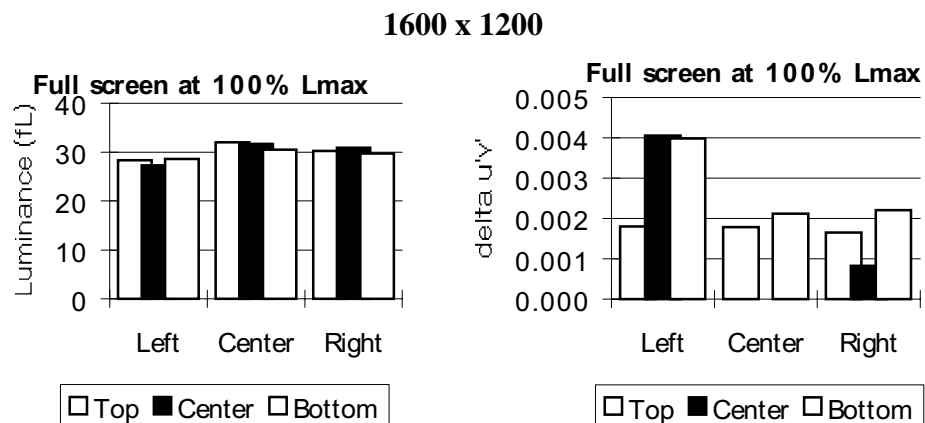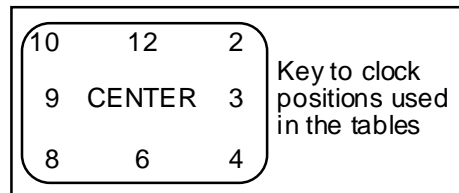*Halation was 5.8 % +/- 0.5% on a small black patch surrounded by a large full white area.*

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer.   The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment: •   Photometer
                 •   Video generator

Test Pattern:

Surround
(L_{white})

0.01% screen area
11-pixel square
(L_{black})
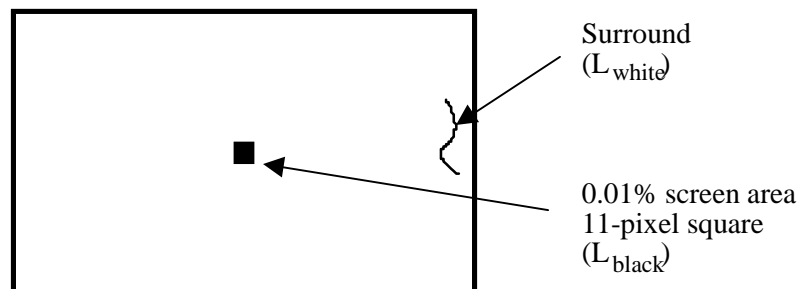
Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that

CRT beam is just on the verge of being cut off. These measurements should be made with a photometer which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video-input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\% \text{ Halation} = L_{black} / (L_{white} - L_{black}) \times 100$$

Where, L_{black}=   measured luminance of interior square
                                 displayed at L_{black} using input count level zero,

              L_{white}=   measured luminance of interior square
                                 displayed at L_{white} using input count level
                                      determined to produce a full screen luminance
                                      of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1600 x 1200 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	1.379 fL ± 4%	1.324 fL to 1.434 fL
Lwhite	23.8 fL ± 4%	22.85 fL to 24.75 fL
Halation	5.8% ± 0.5%	5.3% to 6.3%

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of the measured white point lies within the boundaries accepted by IEC.

Objective: Insure measured screen white of a color monitor has a correlated color
                 temperature (CCT) between 6500K and 9300K.

Equipment: Colorimeter

Procedure: Command screen to Lmax. Measure u'v' chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 Δu'v' of the corresponding CIE
                 daylight, which is defined as follows: If the measured screen white has a CCT
                 between 6500 and 9300 K, the corresponding daylight has the same CCT as the
                 screen white. If the measured CCT is greater than 9300 K, the corresponding
                 daylight is D93. If the measured CCT is less than 6500 K, the corresponding
                 daylight is D65. The following equations were used to compute Δu'v' values
                 listed in table II.5.1:

                 1. Compute the correlated color temperature (CCT) associated with (x,y) by the
                    VESA/McCamy formula: $CCT = 437 n^3 + 3601 n^2 + 6831 n + 5517$,
                    where $n = (x-0.3320)/(0.1858 - y)$. [This is on p. 227 of the FPDM standard]

                 2. If CCT < 6500, replace CCT by 6500. If CCT > 9300, replace CCT by 9300.

                 4. Use formulas 5(3.3.4) and 6(3.3.4) in Wyszecki and Stiles (pp.145-146 second
                    edition) to compute the point (xd,yd) associated with CCT.
                    • First, define $u = 1000/CCT$.
                    • If CCT < 7000, then $xd = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u +$
                    • 0.244063.
                    • If CCT > 7000, then $xd = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u +$
                    • 0.237040.
                    • In either case, $yd = -3.000 xd^2 + 2.870 xd -0.275$.

                 5. Convert (x,y) and (xd,yd) to u'v' coordinates:
                    • $(u',v') = (4x,9y)/(3 + 12y - 2x)$
                    • $(u'd,v'd) = (4xd,9yd)/(3 + 12yd - 2xd)$

                 6. Evaluate delta-u'v' between (u,v) and (ud,vd):
                    • $delta\text{-}u'v' = sqrt[(u' - u'd)^2 + (v' - v'd)^2]$.

                 7. If delta-u'v' is greater than 0.01, display fails the test. Otherwise it passes the
                    test.

Correlated Color Temperature

Error bars denote delta u'v' = 0.010
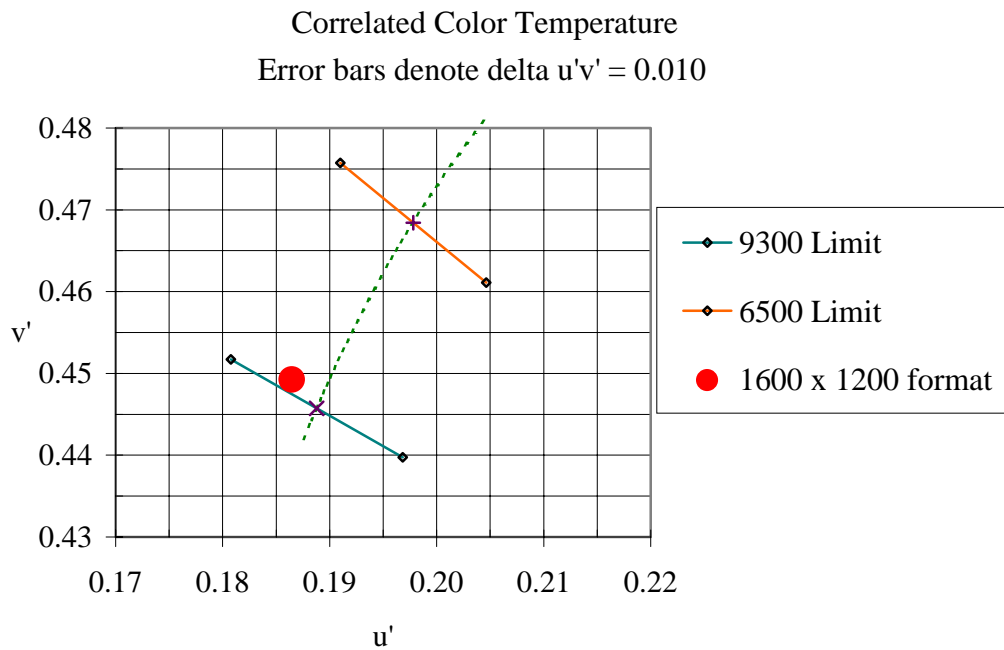
Figure II.5-1 *CCTs of measured whitepoints are within the boundaries required by IEC.*

Table II.5-1 Δu'v' Distances between measured whitepoints and
CIE coordinate values from D_{65} to D_{93}.

	1600 x 1200
CIE x	0.283
CIE y	0.303
CIE u'	0.186
CIE v'	0.449
CCT	9034
delta u'v'	0.003

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Positive increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC
and display software.

Equipment: Photometer

Test targets: Targets are n four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM model to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM model was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.
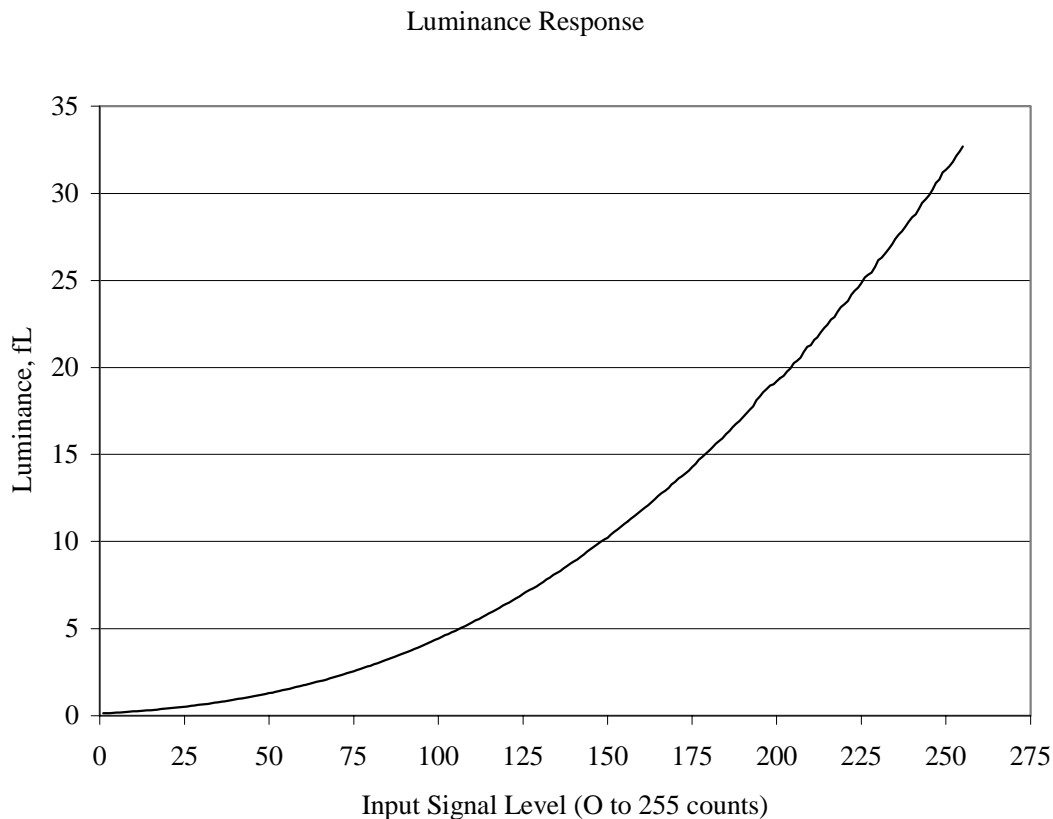
Luminance Response

Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts. Target levels 000 to 127.

Back Ground	Target	L, fL	Diff, fL	Diff, JND	Back Ground	Target	L, fL	Diff, fL	Diff, JND
38	0	0.125	0	0	61	64	1.931	0.049	2
39	1	0.135	0.01	3	61	65	1.983	0.052	2
39	2	0.145	0.01	2	62	66	2.028	0.045	2
39	3	0.156	0.011	2	62	67	2.076	0.048	2
40	4	0.166	0.01	2	62	68	2.135	0.059	2
40	5	0.178	0.012	2	63	69	2.197	0.062	2
41	6	0.189	0.011	3	63	70	2.258	0.061	2
41	7	0.202	0.013	2	63	71	2.316	0.058	3
41	8	0.214	0.012	2	64	72	2.367	0.051	1
42	9	0.227	0.013	2	64	73	2.429	0.062	3
42	10	0.242	0.015	3	64	74	2.497	0.068	2
42	11	0.255	0.013	2	65	75	2.553	0.056	2
43	12	0.27	0.015	2	65	76	2.617	0.064	2
43	13	0.285	0.015	2	65	77	2.678	0.061	2
43	14	0.301	0.016	2	66	78	2.745	0.067	2
44	15	0.317	0.016	2	66	79	2.812	0.067	2
44	16	0.336	0.019	3	66	80	2.873	0.061	2
44	17	0.354	0.018	2	67	81	2.941	0.068	2
45	18	0.373	0.019	3	67	82	3.021	0.08	2
45	19	0.391	0.018	2	67	83	3.088	0.067	2
45	20	0.409	0.018	2	68	84	3.158	0.07	2
46	21	0.429	0.02	2	68	85	3.228	0.07	2
46	22	0.449	0.02	2	69	86	3.289	0.061	2
46	23	0.47	0.021	2	69	87	3.377	0.088	2
47	24	0.492	0.022	3	69	88	3.447	0.07	2
47	25	0.513	0.021	2	70	89	3.526	0.079	2
48	26	0.537	0.024	2	70	90	3.587	0.061	2
48	27	0.558	0.021	2	70	91	3.68	0.093	2
48	28	0.582	0.024	2	71	92	3.745	0.065	2
49	29	0.607	0.025	3	71	93	3.835	0.09	2
49	30	0.633	0.026	2	71	94	3.914	0.079	2
49	31	0.66	0.027	2	72	95	3.998	0.084	2
50	32	0.686	0.026	2	72	96	4.074	0.076	2
50	33	0.712	0.026	2	72	97	4.164	0.09	2
50	34	0.74	0.028	3	73	98	4.253	0.089	2
51	35	0.769	0.029	2	73	99	4.349	0.096	2
51	36	0.797	0.028	2	73	100	4.428	0.079	2
51	37	0.828	0.031	2	74	101	4.524	0.096	2
52	38	0.859	0.031	3	74	102	4.614	0.09	2
52	39	0.89	0.031	2	74	103	4.69	0.076	2
52	40	0.921	0.031	2	75	104	4.787	0.097	2
53	41	0.954	0.033	2	75	105	4.874	0.087	2
53	42	0.99	0.036	2	76	106	4.973	0.099	2
53	43	1.019	0.029	2	76	107	5.062	0.089	1
54	44	1.057	0.038	3	76	108	5.143	0.081	2
54	45	1.093	0.036	2	77	109	5.254	0.111	2
55	46	1.131	0.038	2	77	110	5.364	0.11	2
55	47	1.171	0.04	2	77	111	5.467	0.103	2
55	48	1.204	0.033	2	78	112	5.557	0.09	2
56	49	1.25	0.046	3	78	113	5.642	0.085	1
56	50	1.292	0.042	2	78	114	5.758	0.116	3
56	51	1.333	0.041	2	79	115	5.884	0.126	2
57	52	1.371	0.038	2	79	116	5.966	0.082	1
57	53	1.413	0.042	2	79	117	6.079	0.113	2
57	54	1.454	0.041	3	80	118	6.193	0.114	2
58	55	1.502	0.048	2	80	119	6.304	0.111	2
58	56	1.541	0.039	2	80	120	6.409	0.105	2
58	57	1.585	0.044	2	81	121	6.514	0.105	2
59	58	1.638	0.053	2	81	122	6.626	0.112	1
59	59	1.687	0.049	3	81	123	6.748	0.122	2
59	60	1.733	0.046	2	82	124	6.865	0.117	2
60	61	1.78	0.047	2	82	125	6.99	0.125	2
60	62	1.833	0.053	2	83	126	7.107	0.117	2
60	63	1.882	0.049	2	83	127	7.215	0.108	2

Table II.6-2. System Tonal Transfer at center screen as a function of input counts
Target levels 128 to 255.

Back ground	Target	L, fL	Diff, fL	Diff, JND	Back ground	Target	L, fL	Diff, fL	Diff, JND
83	128	7.298	0.083	1	106	192	17.57	0.21	1
84	129	7.425	0.127	2	106	193	17.77	0.2	2
84	130	7.556	0.131	2	106	194	18.12	0.35	2
84	131	7.682	0.126	1	107	195	18.34	0.22	2
85	132	7.822	0.14	2	107	196	18.58	0.24	1
85	133	7.941	0.119	2	107	197	18.76	0.18	2
85	134	8.076	0.135	2	108	198	18.97	0.21	1
86	135	8.207	0.131	2	108	199	19.04	0.07	0
86	136	8.294	0.087	1	108	200	19.2	0.16	1
86	137	8.458	0.164	2	109	201	19.38	0.18	2
87	138	8.587	0.129	2	109	202	19.52	0.14	1
87	139	8.724	0.137	2	109	203	19.78	0.26	1
87	140	8.84	0.116	1	110	204	19.94	0.16	1
88	141	8.966	0.126	2	110	205	20.26	0.32	2
88	142	9.109	0.143	1	111	206	20.38	0.12	1
88	143	9.264	0.155	2	111	207	20.56	0.18	1
89	144	9.424	0.16	2	111	208	20.89	0.33	2
89	145	9.567	0.143	2	112	209	21.18	0.29	2
90	146	9.704	0.137	2	112	210	21.29	0.11	1
90	147	9.836	0.132	1	112	211	21.58	0.29	1
90	148	9.996	0.16	2	113	212	21.72	0.14	1
91	149	10.12	0.124	1	113	213	22.01	0.29	2
91	150	10.22	0.1	2	113	214	22.28	0.27	2
91	151	10.41	0.19	2	114	215	22.46	0.18	1
92	152	10.56	0.15	1	114	216	22.75	0.29	1
92	153	10.7	0.14	2	114	217	22.89	0.14	1
92	154	10.86	0.16	2	115	218	23.21	0.32	2
93	155	11.01	0.15	1	115	219	23.47	0.26	1
93	156	11.16	0.15	2	115	220	23.64	0.17	1
93	157	11.32	0.16	2	116	221	23.82	0.18	1
94	158	11.46	0.14	1	116	222	24.18	0.36	2
94	159	11.62	0.16	2	116	223	24.4	0.22	2
94	160	11.79	0.17	1	117	224	24.58	0.18	0
95	161	11.94	0.15	2	117	225	24.84	0.26	2
95	162	12.1	0.16	1	118	226	25.18	0.34	2
95	163	12.26	0.16	2	118	227	25.32	0.14	0
96	164	12.44	0.18	2	118	228	25.44	0.12	1
96	165u	12.62	0.18	2	119	229	25.78	0.34	2
97	166	12.78	0.16	1	119	230	26.17	0.39	2
97	167	12.92	0.14	1	119	231	26.3	0.13	0
97	168	13.08	0.16	2	120	232	26.54	0.24	2
98	169	13.28	0.2	2	120	233	26.8	0.26	1
98	170	13.44	0.16	1	120	234	27.06	0.26	1
98	171	13.63	0.19	2	121	235	27.38	0.32	2
99	172	13.76	0.13	1	121	236	27.64	0.26	1
99	173	13.92	0.16	1	121	237	27.82	0.18	1
99	174	14.08	0.16	2	122	238	28.09	0.27	1
100	175	14.28	0.2	1	122	239	28.37	0.28	1
100	176	14.46	0.18	2	122	240	28.64	0.27	2
100	177	14.69	0.23	2	123	241	28.8	0.16	0
101	178	14.86	0.17	1	123	242	29.15	0.35	2
101	179	15.04	0.18	2	123	243	29.45	0.3	1
101	180	15.23	0.19	1	124	244	29.66	0.21	1
102	181	15.42	0.19	2	124	245	29.89	0.23	1
102	182	15.62	0.2	2	125	246	30.2	0.31	2
102	183	15.78	0.16	1	125	247	30.6	0.4	2
103	184	15.94	0.16	1	125	248	30.8	0.2	1
103	185	16.17	0.23	2	126	249	31.2	0.4	1
104	186	16.35	0.18	1	126	250	31.35	0.15	1
104	187	16.56	0.21	2	126	251	31.55	0.2	1
104	188	16.77	0.21	1	127	252	31.8	0.25	1
105	189	16.93	0.16	2	127	253	32.15	0.35	1
105	190	17.14	0.21	1	127	254	32.4	0.25	1
105	191	17.36	0.22	2	128	255	32.7	0.3	2

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern
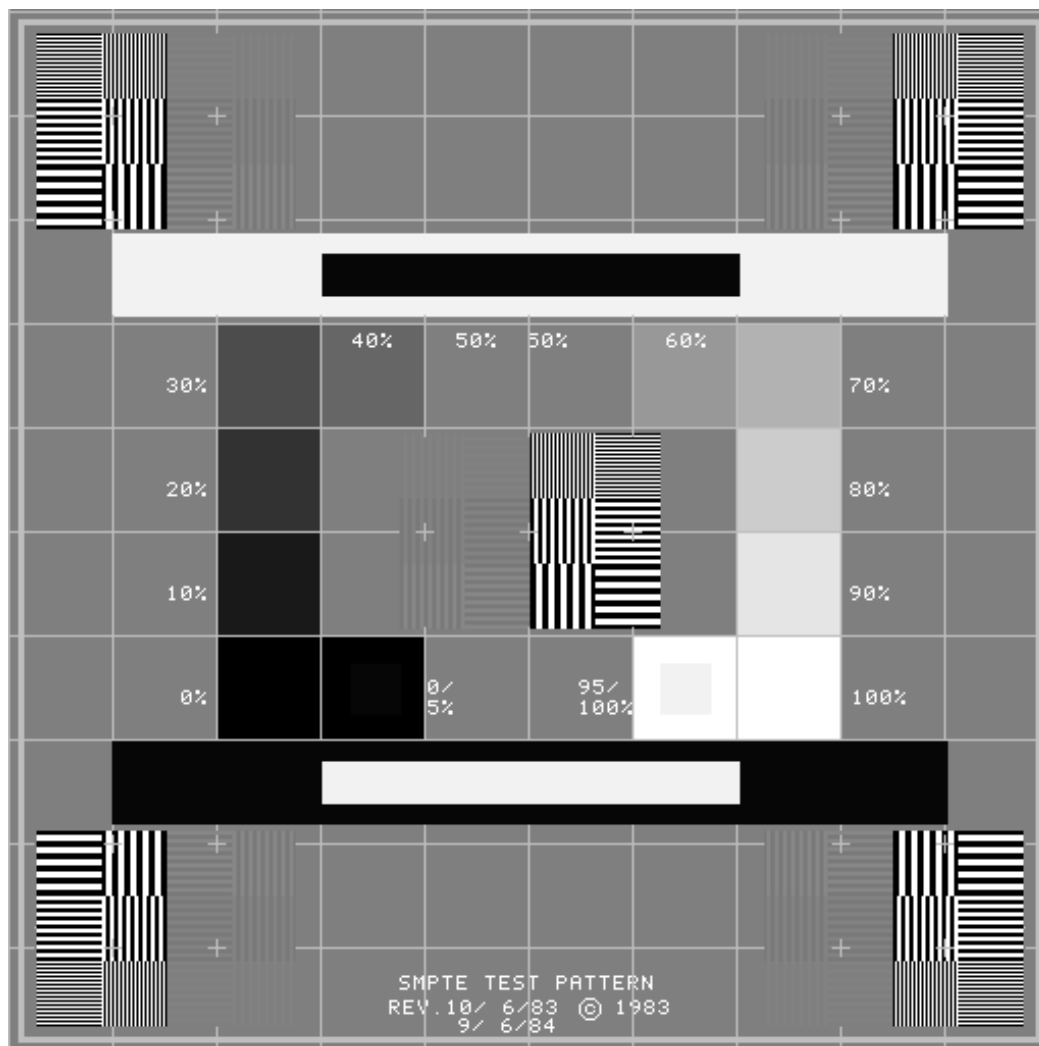
Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts was observed in the MITSUBISHI 2020U monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested formats (HxV): 1600 x 1200 x 72 Hz, and 1024 x 1024 x 110 Hz.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode	Stereo Mode
1600 x 1200	1024 x 1024

II.10.   Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is within 0.5%.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and
                background of 0. Measure horizontal and vertical dimension.

                Alternatively, divide number of addressable pixels by the total image size to
                obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V$\pm$ 6% for pixel density <100 ppi and $\pm$ 10% for pixel density >
                100 ppi.

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches) H x V Pixel Spacing (mils) H x V Pixel Aspect Ratio	15.881 x 11.856 9.93 x 9.88 mils H = V - 0.5%

II.11.   Screen Size (Viewable Active Image)

*Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998,
               Section 501-1.*

Image size for 1600 x 1200 format was 19.818 inches in diagonal.


Objective: Measure beam position on the CRT display to quantify width and height of active
                image size visible by the user (excludes any overscanned portion of an image).

Equipment: • Video generator
                • Spatially calibrated CCD or photodiode array optic module
                • Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines
                each 1-pixel wide. Lines in test pattern are displayed at 100% L$_{max}$ must be

positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).
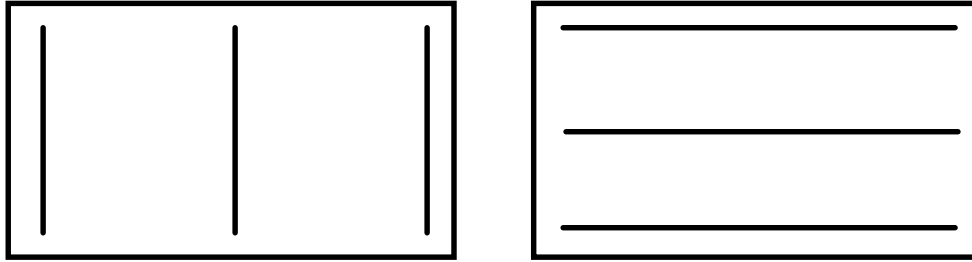
1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square-root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Modes
Addressability (H x V)	1600 x 1200
H x V Image Size (inches)	15.881 x 11.856
Diagonal Image Size (inches)	19.818

II.12.   Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

> *Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 30% in Zone A of diameter 7.6 inches, and exceeded Cm = 16% in Zone B. Cm dropped to 23% for Zone A diameter of 9.79 inches (40% of image area). Moiré cancellation degraded Cm to Cm = 27% in Zone A of diameter 7.6 inches, Cm = 20% for Zone A diameter of 9.79 inches (40% of image area) and Cm = 14% in Zone B.*

Objective: Quantify contrast modulation as a function of screen position.

Equipment: • Video generator
              • Spatially calibrated CCD or photodiode array optic module
              • Photometer with linearized response

Procedure: The maximum video modulation frequency for each format (1280 x 1024, 1620 x 1024, 1920 x 1200) was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax.

              Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 51% in Zone A, and is equal to or greater than 35% in Zone B.

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

Use or disclosure of data on this sheet is subject to the restrictions on the cover and title of this report.

The sample contrast modulations shown in Figure II.12-1 for two different color CRTs are not fully realized because of the presence of moiré caused by aliasing between the image and the shadowmask. Because contrast modulation values are calculated for the maximum peak and minimum valley luminance levels as indicated in the sample data shown, they do not include the degrading effects of aliasing.
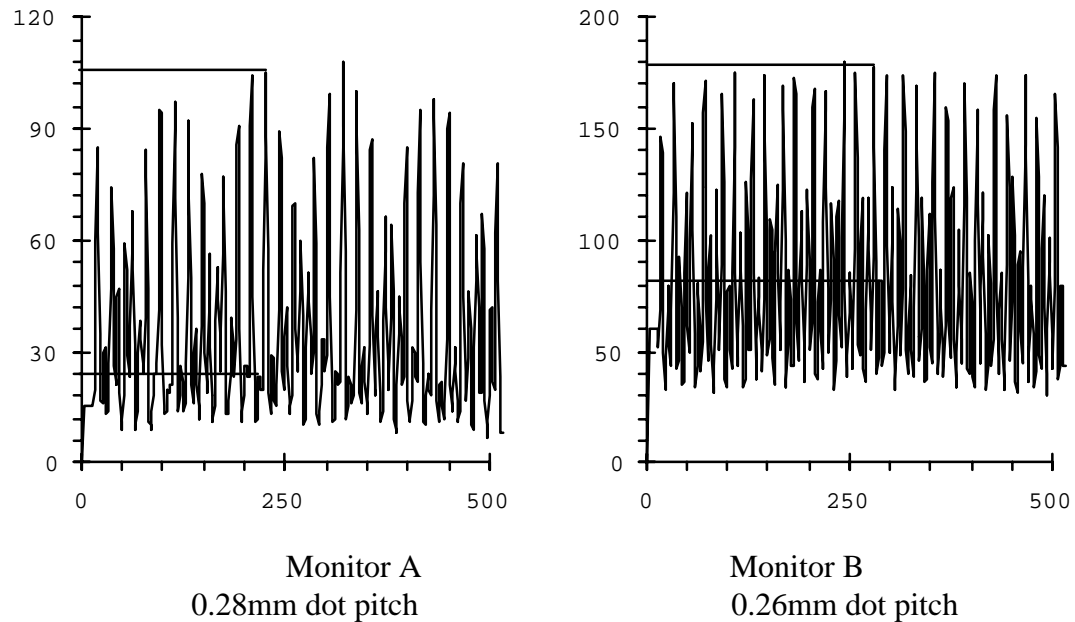

Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Figure II.12-1. *Contrast modulation for sample luminance profiles (1 pixel at input level corresponding to 50% Lmax, 1 pixel at level 0 = Lmin) for monitors exhibiting moiré due to aliasing.*

Table II.12-1. Contrast Modulation
Corrected for lens flare and Zone Interpolation

Moiré Cancellation OFF

Zone A = 7.6-inch diameter circle for 24-degree subtended circle at 18-inches viewing distance

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	42%	55%			16%	80%			59%	67%
			50%	72%	30%	81%	56%	77%		
Major	73%	72%	63%	77%	54%	83%	70%	74%	88%	65%
			60%	78%	50%	78%	60%	74%		
Bottom	68%	71%			48%	76%			68%	61%

Zone A = 9.79-inch diameter circle for 40% area

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	42%	55%			16%	80%			59%	67%
			48%	69%	23%	81%	56%	75%		
Major	73%	72%	66%	76%	54%	83%	75%	72%	88%	65%
			61%	77%	49%	77%	61%	72%		
Bottom	68%	71%			48%	76%			68%	61%

Moiré Cancellation ON

Zone A = 7.6-inch diameter circle for 24-degree subtended circle at 18-inches viewing distance

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	38%	36%			14%	49%			58%	50%
			45%	46%	27%	50%	53%	51%		
Major	71%	47%	60%	50%	50%	52%	67%	52%	85%	51%
			53%	49%	48%	52%	56%	48%		
Bottom	58%	43%			47%	52%			65%	40%

Zone A = 9.79-inch diameter circle for 40% area

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	38%	36%			14%	49%			58%	50%
			44%	44%	20%	49%	54%	51%		
Major	71%	47%	63%	49%	50%	52%	71%	52%	85%	51%
			54%	48%	47%	52%	58%	46%		
Bottom	58%	43%			47%	52%			65%	40%

II.13.   Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was 101 ppi as tested for the 1600 x 1200-line addressable format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and
                   horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
H x V Addressability, Pixels	1600 x 1200
H x V Image Size, Inches H x V Pixel Density, ppi	15.881 x 11.856 101 x 101 ppi

II.14.   Moiré

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Phosphor-to-pixel spacing ratios are less than 1.0 at screen center for the 1600 x 1200 format (ratio varies from 0.99 at center to 1.07 at side edges of screen). Compensation circuitry effectively reduces the visibility of moiré patterns when displaying 1-on/1-off vertical grille patterns, but reduces contrast modulation, Cm (see II.12 Contrast Modulation).

Objective: Determine lack of moiré.

Equipment   Loupe with scale graduated in 0.001 inch or equivalent

Procedure   Measure phosphor pitch in vertical and horizontal dimension at screen center. For aperture grille screens, vertical pitch will be 0. Define pixel size by 1/pixel density.

Data: Define value of phosphor: pixel spacing. Value <1 passes, but <0.6 preferred.

Table II.14-1. Phosphor-to-Pixel-Spacing Ratios

	Monoscopic Mode
Addressability	1600 x 1200
Phosphor Pitch	0.25mm to 0.27 mm, horizontal grille
Pixel Spacing	9.93 mils, horizontal
Phosphor-to-Pixel-Spacing	0.99 to 1.07

Discussion: Moiré occurs when the phosphor pitch is too large in comparison to the pixel size. Studies have shown that a phosphor pitch of about 0.6 pixels or less is required for adequate visibility of image information without interference from the phosphor structure.
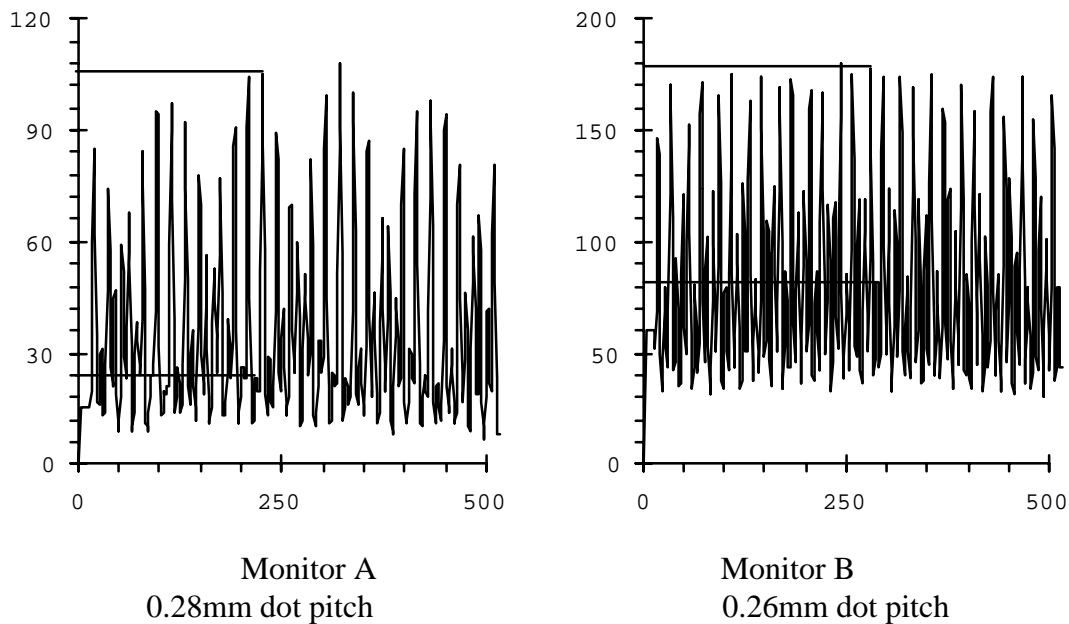
Monitor A	Monitor B
0.28mm dot pitch	0.26mm dot pitch

Figure II.14-1. *Contrast modulation for sample luminance profiles (1pixel at level 50, 1 pixel at level 0) for monitors exhibiting moiré due to aliasing.*

In Figure II.14-1, Monitor A phosphor pitch is 0.90 pixels as compared with 0.84 pixels in Monitor B. Moiré is more visible in Monitor A, appearing as long stripes where contrast modulation has been degraded. In Monitor B, moiré is less visible, appearing as "fish-scales" where contrast modulation has been reduced. Even though the Monitor A exhibits a greater loss of contrast modulation from the presence of moiré on 1-on/1-off vertical grille patterns, there is little or no visual impact when aerial photographic images are displayed. NIDL experts in human vision and psychophysics were unable to discern presence of moiré on either monitor when grayscale imagery was displayed.

II.15.   Straightness

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.3% of the image width or height.

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment: • Video generator
                     • Spatially calibrated CCD or photodiode array optic module
                     • Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and
                horizontal lines each 1-pixel wide. Lines in test pattern are displayed at
                100% L_{max} must be positioned along the top, bottom, and side edges of
                the addressable screen, as well as along both the vertical and horizontal
                centerlines (major and minor axes).
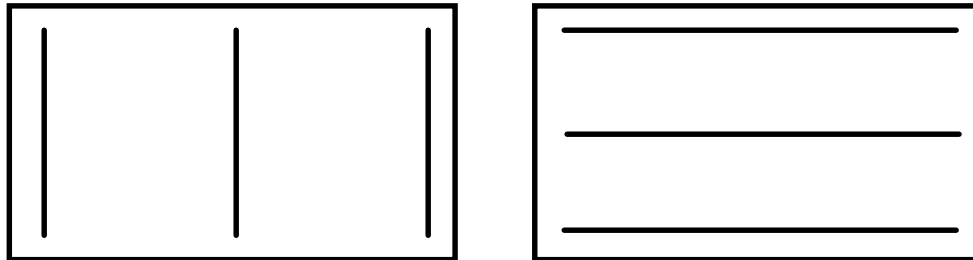
1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.
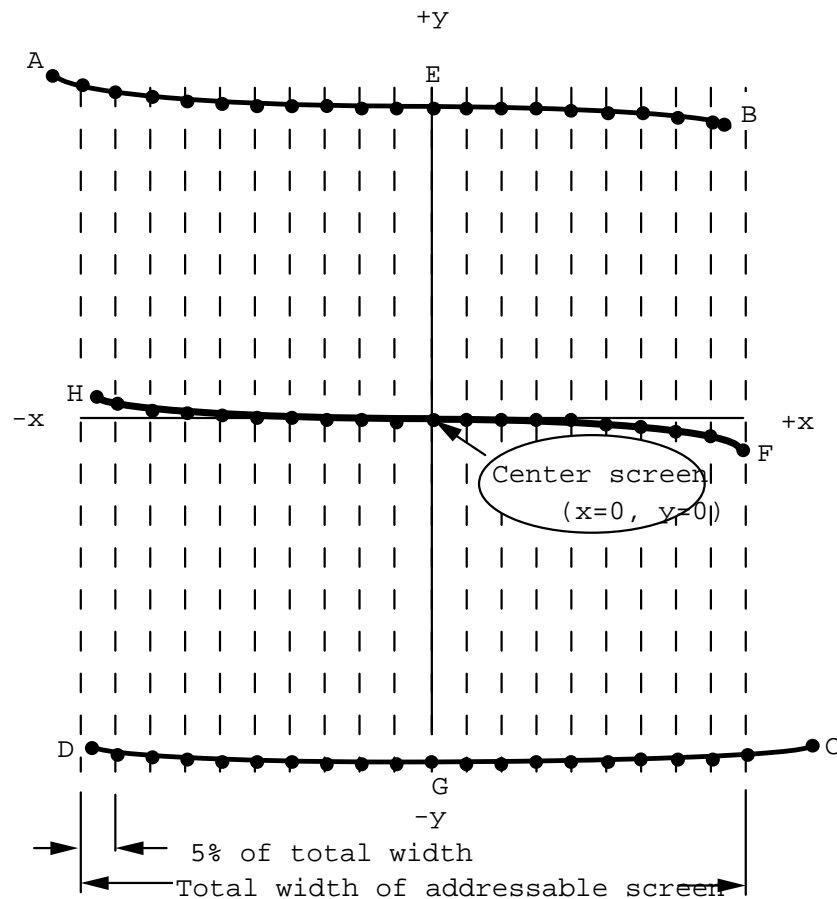
Figure II.15-2 Measurement locations for waviness along horizontal lines.
Points A, B, C, D are extreme corner points of addressable screen. Points E,
F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates along the length of a nominally straight line. Measure x,y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x,y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-I. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Straightness
Tabulated x,y positions at 5% addressable screen increments
along nominally straight lines.

| Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-7833	5922	-7854	-5900	-7850	-19	-40	5957	-7845	5910	8054	5942
-7200	5925	-7200	-5903	-7200	-23	-32	5400	-7845	5400	8051	5400
-6400	5927	-6400	-5903	-6400	-21	-26	4800	-7851	4800	8055	4800
-5600	5926	-5600	-5899	-5600	-18	-20	4200	-7858	4200	8059	4200
-4800	5927	-4800	-5894	-4800	-18	-16	3600	-7862	3600	8063	3600
-4000	5927	-4000	-5893	-4000	-16	-12	3000	-7862	3000	8065	3000
-3200	5929	-3200	-5894	-3200	-12	-8	2400	-7864	2400	8065	2400
-2400	5930	-2400	-5896	-2400	-13	-6	1800	-7864	1800	8062	1800
-1600	5930	-1600	-5900	-1600	-10	-2	1200	-7860	1200	8056	1200
-800	5926	-800	-5906	-800	-5	-1	600	-7858	600	8052	600
0	5926	0	-5909	0	0	0	0	-7857	0	8047	0
800	5926	800	-5912	800	-2	-2	-600	-7857	-600	8041	-600
1600	5927	1600	-5917	1600	-2	-3	-1200	-7860	-1200	8036	-1200
2400	5929	2400	-5917	2400	-4	-8	-1800	-7863	-1800	8034	-1800
3200	5932	3200	-5917	3200	-5	-9	-2400	-7869	-2400	8035	-2400
4000	5935	4000	-5915	4000	-8	-13	-3000	-7872	-3000	8035	-3000
4800	5939	4800	-5923	4800	-8	-15	-3600	-7875	-3600	8035	-3600
5600	5945	5600	-5929	5600	-8	-19	-4200	-7875	-4200	8035	-4200
6400	5950	6400	-5932	6400	-8	-19	-4800	-7871	-4800	8035	-4800
7200	5949	7200	-5932	7200	-8	-21	-5400	-7864	-5400	8027	-5400
8054	5949	8016	-5927	8035	-8	-22	-5926	-7850	-5904	8016	-5928

1600 x 1200
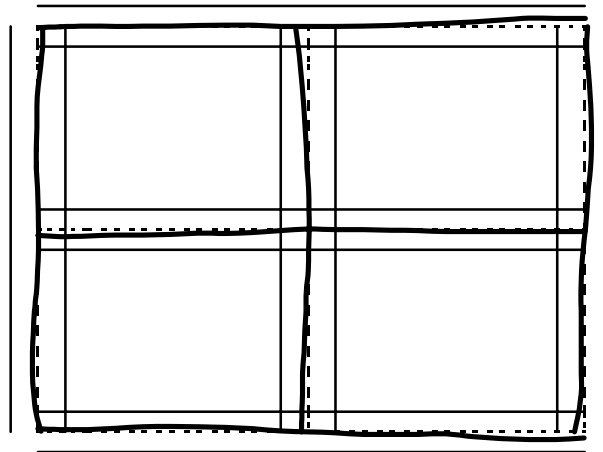
Figure II.15-3 Waviness of Mitsubishi 2020u color monitor in 1280 x 1024, 1620 x 1024, and 1920 x 1200 modes. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for 1600 x 1200 format was set to 72 Hz. Vertical refresh rate for the 1024 x 1024 stereo format was 110 Hz, limited by the monitor.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Monoscopic Mode	**Stereo Mode**
Addressability	1600 x 1200	1024 x 1024
Vertical Scan	72 Hz	110 Hz
Horizontal Scan	89.3 kHz	120 kHz

II.17.   Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio averaged 11.1 to 1 (10.3 right, 11.8 left) at screen center. Luminance of white varied by up to 21.8% across the screen. Chromaticity variations of white were less than 0.017 delta u'v' units.

Objective: Measure stereo extinction ratio

Equipment: Two "stereo" pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

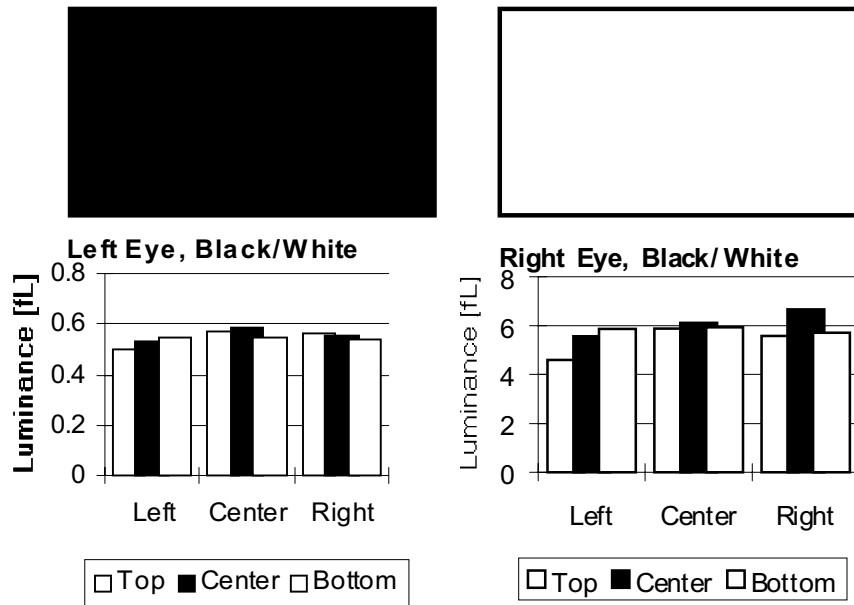Stereo extinction ratio is average of left and right ratios defined above.

Fig.II.17-1. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.
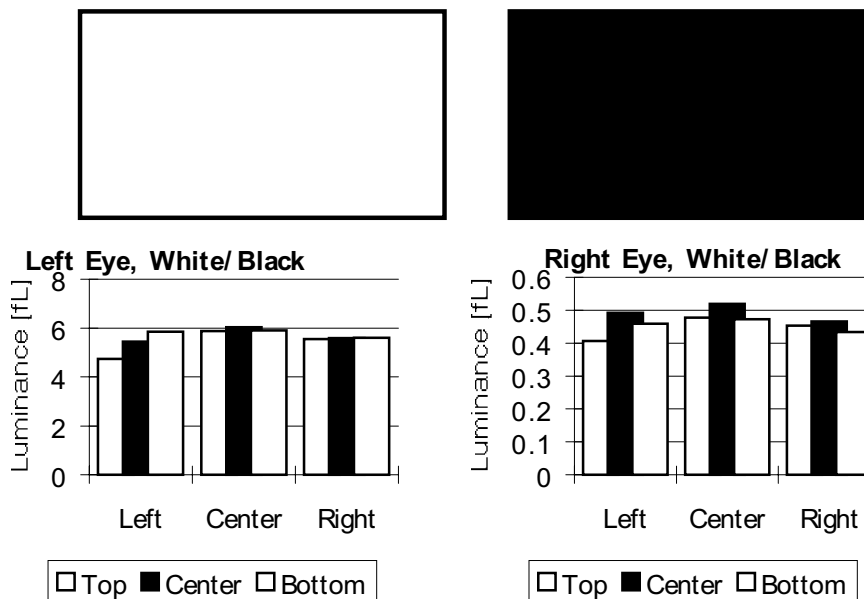

Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.
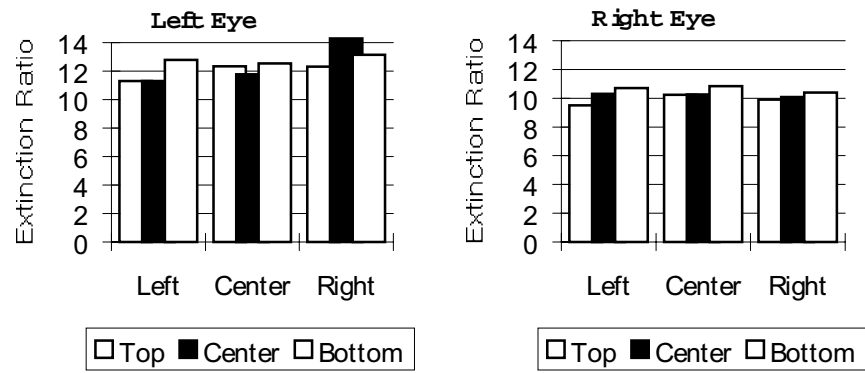
Fig.II.17-3. Spatial Uniformity of extinction ratio in stereo mode.

Fig.II.17-4 Spatial uniformity of chromaticity of white in stereo mode.

II.18.   Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 1.25% of full screen.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment: • Video generator
              • Spatially calibrated CCD or photodiode array optic module
              • Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.
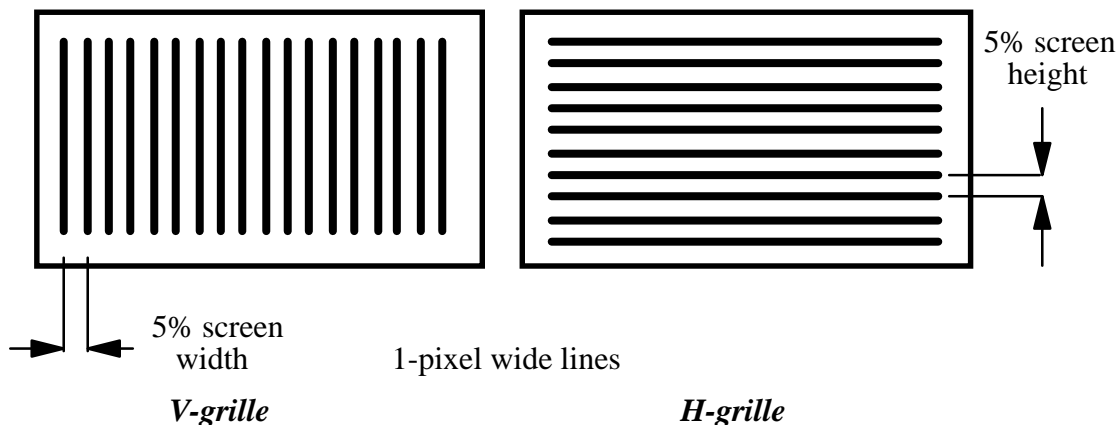

5% screen width   1-pixel wide lines   5% screen height

V-grille   *H-grille*

Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x,y-translation stage to measure screen x,y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.
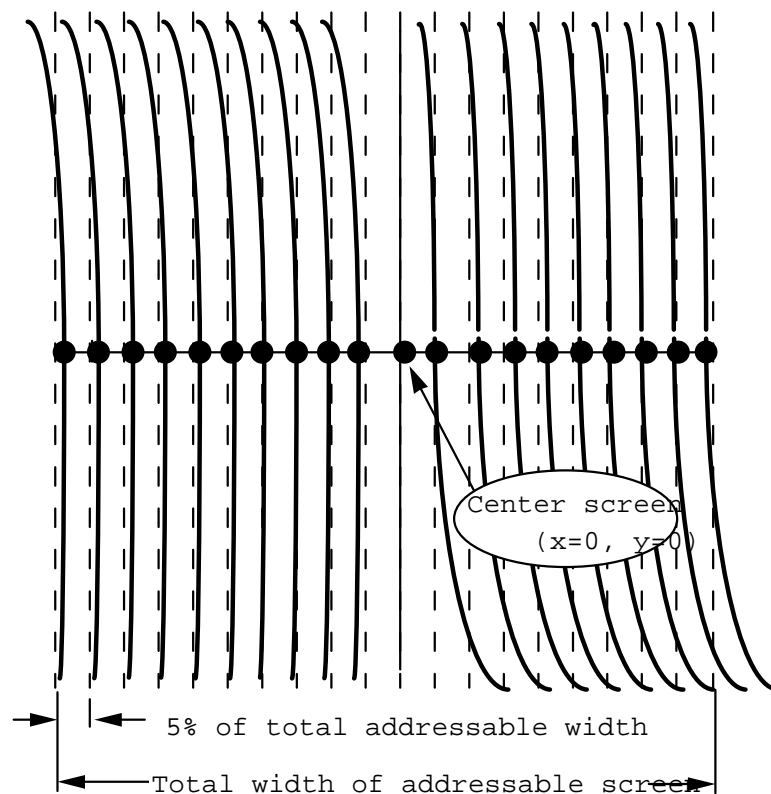
Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

Data: Tabulate x, y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impact the absolute position of each pixel on the screen and are, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figures II.18-3 and II.18-4.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	1.25%	1.19%	0.13%	0.16%

Table II.18-2. Horizontal and Vertical Nonlinearities Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	Right Side	Top	Bottom
-7902	7893	5812	-5828
-7072	7109	5226	-5248
-6257	6311	4640	-4667
-5454	5509	4056	-4083
-4662	4706	3471	-3500
-3877	3905	2893	-2917
-3095	3112	2320	-2333
-2317	2325	1741	-1751
-1541	1545	1163	-1164
-770	771	583	-579
0	0	0	0

**Horizontal Pixel position accuracy
relative to center**
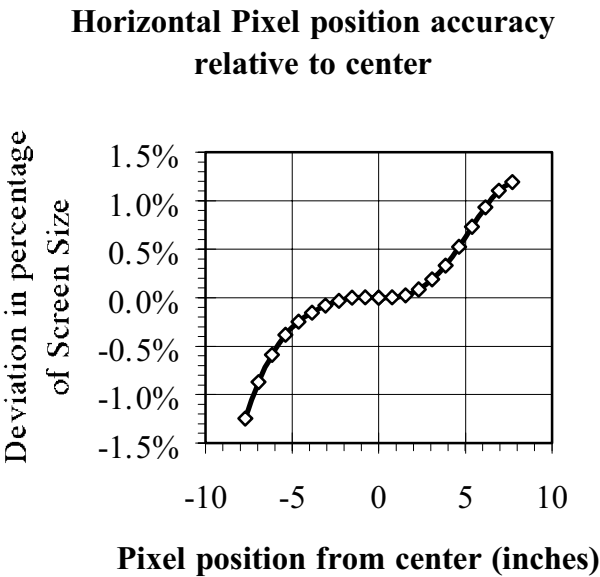
Fig. II.18-3   Horizontal linearity characteristic.

**Vertical pixel position accuracy
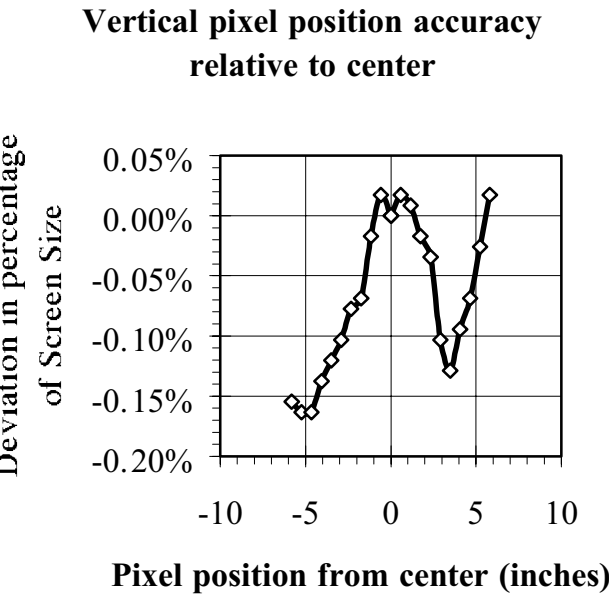relative to center**

Fig. II.18-4   Vertical linearity characteristic

II.19.   Jitter/Swim/Drift

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.


Maximum jitter and swim/drift was 3.2 mils and 4.4 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of
                the CRT display. Quantify the effects of perceptible time varying raster
                distortions: jitter, swim, and drift. The perceptibility of changes in the
                position of an image depends upon the amplitude and frequency of the
                motions, which can be caused by imprecise control electronics or external
                magnetic fields.

Equipment: • Video generator
                • Spatially calibrated CCD or photodiode array optic module
                • Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and
                horizontal lines each 1-pixel wide. Lines in test pattern must be
                positioned along the top, bottom, and side edges of the addressable
                screen, as well as along both the vertical and horizontal centerlines
                (major and minor axes).
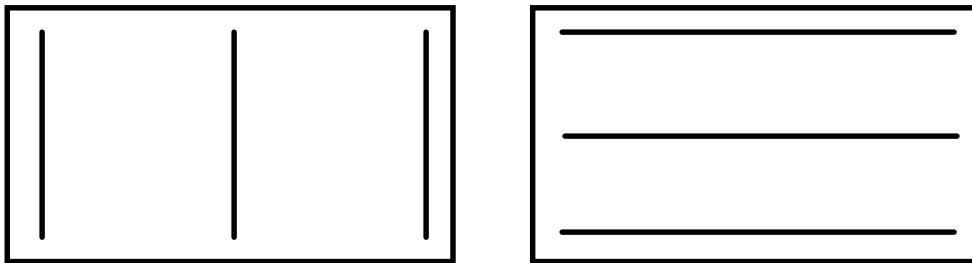
V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and
                horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift
                (over 60 seconds) over a 2.5 minute duration as displayed using grille
                video test patterns. Generate a histogram of raster variance with time. The
                measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift
Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.
1600 x 1200 x 72hz

		H-lines		V-lines		
		Moiré ON	Moiré OFF	Moiré ON	Moiré OFF	
10D corner	Max Motions					
	Jitter	3.37	3.49	3.08	2.58	
	Swim	4.08	3.96	3.36	3.3	
	Drift	4.71	4.00	3.56	3.24	
Black Tape	Max Motions					
	Jitter	0.272		0.587		
	Swim	0.276		0.604		
	Drift	0.315		0.604		
Less Tape Motion						maximums
	Jitter	3.10	3.22	2.49	1.99	3.22
	Swim	3.80	3.68	2.76	2.70	3.80
	Drift	4.40	3.69	2.96	2.64	4.40

II.20 Warm-up Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 41 minute warm-up was necessary for luminance stability of Lmin = 0.086 fL + 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

                    The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1280 x 1024 format in graphical form. The luminance remains very stable after 41 minutes.
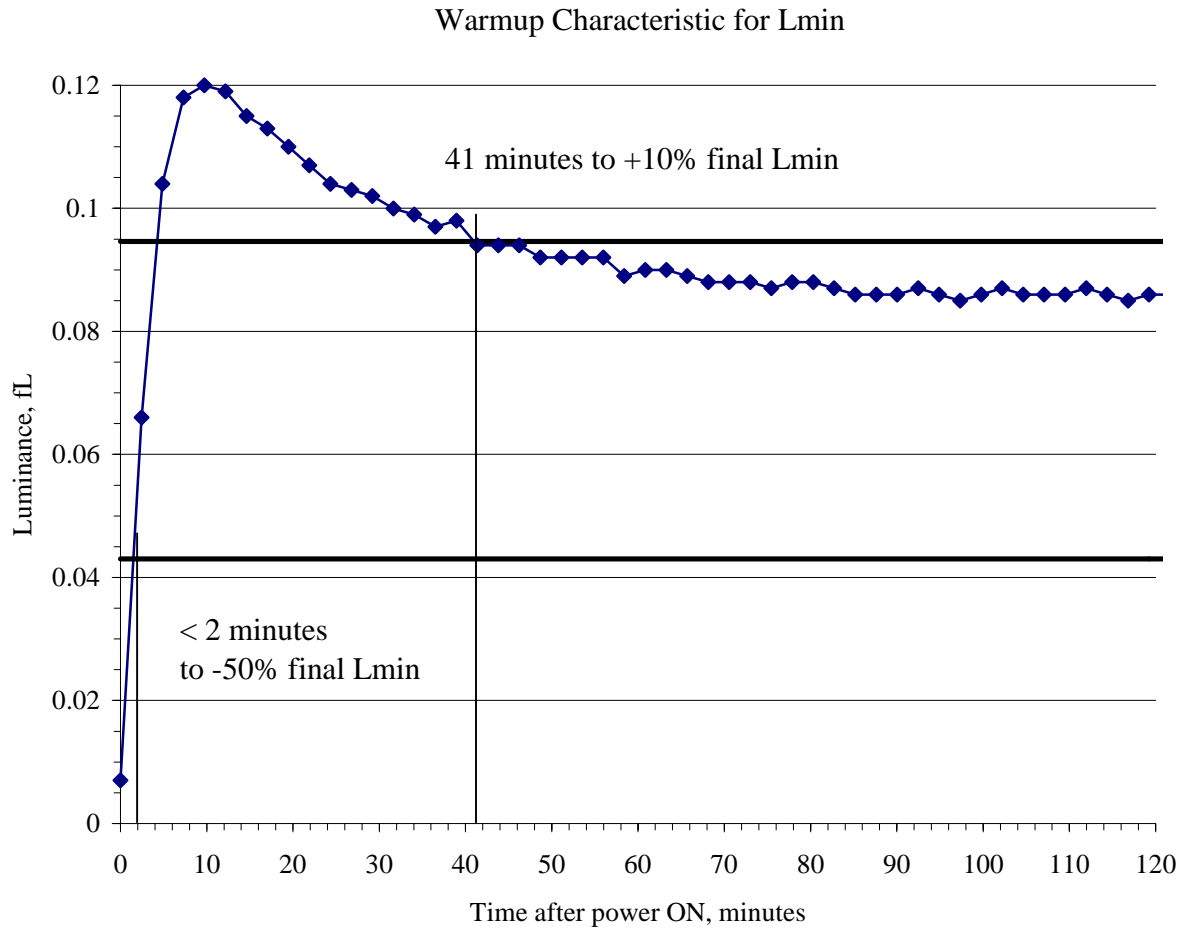
Warmup Characteristic for Lmin

Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with
an input count of 0. (Note suppressed zero on luminance scale).